Ministry of Transportation
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ELECTROMAGNETIC CONDUCTIVITY MEASUREMENTS FOR AGGREGATE PROSPECTING

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ELECTROMAGNETIC CONDUCTIVITY MEASUREMENTS FOR AGGREGATE PROSPECTING

Author(s): S.I. SZOKE and Z.L. KATONA

Abstract:

Aggregate deposit investigations are a significant component of provincial highway construction in Ontario. Greater importance has been placed on the effectiveness of aggregate deposit investigations in recent years as availability of good quality aggregate deposits is increasingly limited due to urban expansion and environmental concerns. The use of an electromagnetic conductivity instrument by skilled operators can increase the quality of aggregate deposit information obtained. Cost efficiency is achieved by the elimination of less promising areas within aggregate deposits, thus reducing the cost of excavating test pits by power equipment. This report documents recent Ministry of Transportation experience with the use of electromagnetic conductivity measurements for this purpose.

Résumé:

Les études sur les gisements d'agrégats sont un élément important de la construction des routes provinciales en Ontario. Depuis quelques années, on accorde une plus grande importance à l'efficacité de ces études car les gisements de bonne qualité sont de plus en plus rares en raison de l'expansion urbaine et des mesures de protection de l'environnement. L'utilisation d'un instrument de lecture de la conductivité électromagnétique par une personne qualifiée peut améliorer la qualité des renseignements sur les gisements d'agrégats. En éliminant les parties les moins intéressantes des gisements, ce qui permet de réduire les coûts de creusage mécanique de puits de reconnaissance, on assure la rentabilité du processus. Le présent rapport documente les activités récentes du ministère des Transports dans la mesure de la conductivité électromagnétique pour la prospection d'agrégats.

Keywords: aggregates, prospecting, geophysical investigations, electromagnetic conductivity

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ELECTROMAGNETIC CONDUCTIVITY MEASUREMENTS FOR AGGREGATE PROSPECTING

by

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Table of Contents

	Page
Introduction	1
Field Procedures	2
Data Interpretation	3
Discussion	3
Conclusions	5
Recommendations	6
Acknowledgements	6
References	7
Appendix A: Data Presentation	8

Figures

1	Ice-Contact Deposit, Line 1, Carlyle Twp., N. Ontario	9
2	Ice-Contact Deposit, Line 2, Carlyle Twp., N. Ontario	10
3	Lacustrine Plain Deposit, Line 1, Oliver Twp. Mun., N. Ontario	11
4	Esker-Kame Complex, Line 1, Goldie Twp., N. Ontario	12
5	Esker-Kame Complex, Line 2, Goldie Twp., N. Ontario	13
6	Outwash Deposit, Line 1, Sullivan Twp., S. Ontario	14
7	Outwash Deposit, Line 2, Sullivan Twp., S. Ontario	15
8	Beach Deposit, Line 1, Sidney Twp., S. Ontario	16
9	Esker Deposit, Line 1, Sidney Twp., S. Ontario	17
10	Beach Deposit, Line 1, Brighton Twp., S. Ontario	18
11	Esker-Drumlin Complex, Line 1, Asphodel Twp., S. Ontario	19

Photographs

1	EM-31 Survey, 3 m Ground Penetration Reading	20
2	EM-31 Survey, 5 m Ground Penetration Reading	20
3	EM-31 Survey, 6 m Ground Penetration Reading	21
4	Correlation of EM-31 Survey Data with Test Pit	21

ELECTROMAGNETIC CONDUCTIVITY MEASUREMENTS FOR AGGREGATE PROSPECTING

INTRODUCTION

Location, delineation, and evaluation of aggregate deposits for road construction projects is an ongoing activity of the Aggregate Unit Staff of the Regional Geotechnical Sections of the Ministry of Transportation, Ontario (MTO). As a result of intensified urban expansion, environmental concerns, and consequent elimination of readily accessible good quality aggregate deposits, this activity has become increasingly challenging. To alleviate this situation in certain areas of the province, research and development work at Head Office was initiated during the mid 1980's. The purpose of this was to evaluate new methods and improved techniques of aggregate deposit investigation by taking advantage of recent advances in the fields of remote sensing and geophysics [1]. This initiative resulted in the development of an electromagnetic (EM) ground conductivity technique [2] and field manual [3] for locating buried granular deposits. In order to enhance technical expertise in the regions, it was recommended that Aggregate Unit Field Staff be given hands-on training in the use of the EM-31 instrument, field survey methods, and data interpretation [2, 3].

The EM-31 is a patented, Canadian-made, engineering geophysics instrument. It was designed as an alternative to conventional resistivity techniques. Conventional resistivity techniques involve placing electrodes in the ground. EM-31 employs the use of electromagnetic techniques for the measurement of ground conductivity. The instrument contains a transmitter and a receiver with an intercoil spacing of 3.7 m. When the transmitter is energized with an alternating current at an audio frequency, a primary magnetic field is created. This, in turn, induces very small currents in the ground. These currents, in turn, generate a secondary magnetic field which is sensed, together with the primary field, by the receiver coil. In general, the secondary magnetic field is a function of intercoil spacing, operating frequency, and the ground conductivity [4, 5]. Apparent ground conductivity is displayed by the instrument gauge and recorded by the operator.

In 1990, Head Office acquired an EM-31 instrument [6] to improve the effectiveness of aggregate deposit investigations. This report documents Aggregate Unit Field Staff training and experience with the EM-31 instrument during 1990 and 1991.

FIELD PROCEDURES

During 1990, all five MTO regions were visited, and the EM-31 instrument was introduced to the Aggregate Unit Field Staff during the course of routine aggregate deposit investigations. Field staff were asked to select aggregate deposits where the use of this instrument could be best evaluated and the geophysical information obtained would be beneficial for the investigation.

Near-surface aggregate deposits were targeted, as these deposits are the most commonly-used sources of construction aggregate materials. Additional human resources requirements were minimal because of the operational capabilities of the EM-31 instrument during the investigation of these types of deposits. Field activities included demonstration of the use of the instrument by Head Office staff, followed by hands-on training of Aggregate Unit Field Staff during actual aggregate deposit investigations. This method of training was preferred, in order to assess the impact of the use of this instrument on the long established conventional routine of aggregate investigations. Comments were solicited from the field staff regarding their experience with the instrument. Special effort was made to demonstrate the instrument in different overburden conditions and aggregate deposit types. The instrument was also demonstrated under a variety of climatic conditions which included warm, cold, dry, and wet environments. Field surveys were conducted along lines and grids of previous or proposed test pit sites, in accordance with the operations manual [6]. Instrument readings were taken at 10 m intervals at a 3 m, 5 m, and 6 m depth of ground penetration. Photographs 1 to 3 in Appendix A illustrate the appropriate instrument position for these respective readings. A minimum of 500 m of EM-31 survey lines were completed in each region.

Surveys were conducted in each region on deposits believed to contain aggregate material, based on prior geological knowledge or power equipment investigation. For this reason, additional new information related to aggregate deposit consistency, continuity between test pits, thickness, uniformity, depth to water table, and depth to bedrock or non-aggregate material were of major interest.

EM-31 survey data obtained in the field is a reading of apparent ground conductivity expressed in millimhos/metre (mmho/m) at each survey station [6]. The EM-31 instrument is capable of providing apparent ground conductivity readings to a depth of 6 m. Reference readings of conductivities of different materials were taken in each project area. In the aggregate deposit surveys, the instrument was positioned to provide apparent ground conductivity readings as described above. This survey method allowed better

interpretations of deposit consistency and variability with depth. Correlation at each deposit was accomplished by comparing test pit information with interpreted EM-31 survey data (Photograph 4).

DATA INTERPRETATION

EM-31 survey data are presented in the form of conductivity versus distance plots. In these plots, the relative magnitude and variability of ground conductivity or lack of it was interpreted as an indicator of the type of material the instrument encountered. Readings of conductivity can be contoured for a whole deposit area based on a grid pattern of survey lines.

Appendix A contains selected EM-31 plots of electromagnetic conductivity and interpreted schematic cross-sections of typical aggregate deposits investigated in both southern and northern Ontario (Figures 1 to 11). Deposits are not identified beyond geological origin and township name, in order to protect the identity of landowners as some surveys were conducted on private land. These plots and Photographs 1 to 4 can provide a useful general reference to Aggregate Unit Field Staff when conducting EM-31 surveys in the future on aggregate deposits of similar geological origin.

DISCUSSION

Ministry experience with the EM-31 instrument indicates that it cannot replace conventional methods of investigating aggregate deposits. It is seen, however, as a modern tool capable of improving the existing method by reducing time and financial resources required to obtain information. It can increase the confidence of Aggregate Unit Field Staff about the quality of data collected. It is also capable of reducing the potential for presentation of erroneous information for aggregate sources shown on the Aggregate Sources Lists [7], therefore reducing the possibilities for claims by the contractor. This is a significant improvement, especially in the case of non-uniform deposits, in which areas of low economic aggregate potential need to be eliminated before resources are spent on test pit investigations. The following observations by Head Office and regional staff summarize ministry experience with the investigation method using this instrument.

Advantages

- It is simple and easy to use.
- It is highly portable, and can fit into the trunks of most fullsize and compact cars.
- It is relatively light, and may be carried for several hours by the operator without great fatigue.
- It may have potential in augmenting soil surveys.
- It can differentiate aggregate materials from clay and till.
- It can differentiate bedrock from clay and till.
- It can detect the presence of organic material.
- It can detect high fines and high moisture content in aggregate deposits.
- It can differentiate between materials to a depth of 6 m.
- Weather does not affect the instrument.
- The instrument is durable and relatively inexpensive ($14,500 including tax in 1991 dollars).
- It can carry out non-destructive testing to protect farmer's fields, potential archaeological sites, etc.
- It can detect buried cables, pipes, etc. prior to test pitting.

Disadvantages

- It cannot precisely distinguish between aggregate and bedrock of similar petrographic composition. This is beyond the sensitivity of the instrument.
- It cannot precisely distinguish between clean sand and clean gravel. This is beyond the sensitivity of the instrument.
- In areas where the silt and water content of the granular deposit is relatively high, the apparent conductivity is higher than that which would normally be expected for granular material. This makes it more difficult

to detect the presence of granular material from the apparent conductivity data obtained.

- Excessive condensation/moisture in the instrument can be a problem.

CONCLUSIONS

The following conclusions are drawn from comparison of EM-31 survey data with test pit information obtained from the aggregate deposits investigated and the personal experiences of Aggregate Unit Field Staff who used the instrument.

- For preliminary reconnaissance level aggregate deposit surveys, a 5 m depth penetration of the instrument with continuous monitoring of conductivity readings is considered sufficient.

- The instrument can detect areas of aggregate material during preliminary investigation prior to power equipment work.

- It can delineate the boundary/extent of aggregate deposits by being able to survey large areas rapidly.

- It can predict material consistency to a depth of 6 m.

- It can eliminate areas where further work would be wasteful.

- It can provide supplementary information between test pits regarding continuity of aggregate material.

- It can provide cost-efficiency by reducing the number of test pits required in aggregate deposits.

- It cannot be used alone to determine depth to bedrock.

It can easily be adapted to current work practices of Aggregate Unit Field Staff.

RECOMMENDATIONS

1. Aggregate Unit Field Staff should use electromagnetic conductivity measurements for investigating new aggregate deposits and problem aggregate deposit situations related to geological origin.

2. Expertise to use the EM-31 instrument should be maintained in the regions.

3. Applicability of the use of the EM-31 instrument for soils applications should be investigated.

4. Alternate methods for determination of depth to bedrock should be investigated.

5. The instrument should be stored in a dry place overnight before use.

ACKNOWLEDGEMENTS

The work presented in this report was made possible by the co-operation and assistance of Aggregate Unit Field Staff of the Regional Geotechnical Sections. We wish to thank C. Barber, D. Billings, D. Fox, M. Gibbens, J. Rogerson, and their field staff for participation in the field surveys, and J. Pretty for wordprocessing.

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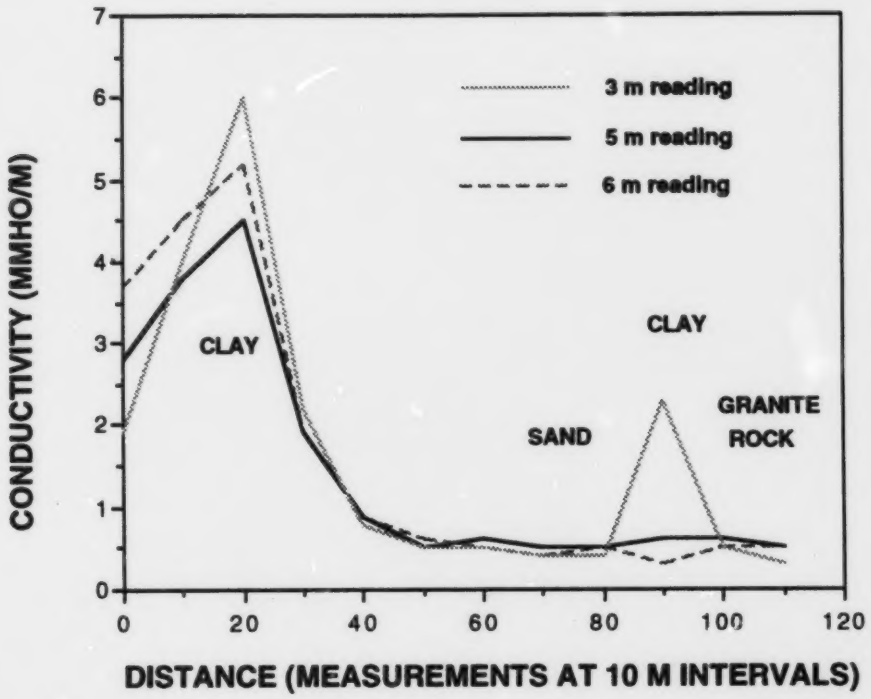
[6] Geonics Ltd., 1979; EM-31 Operating Manual; Geonics Ltd., Mississauga, Ontario, 58p.

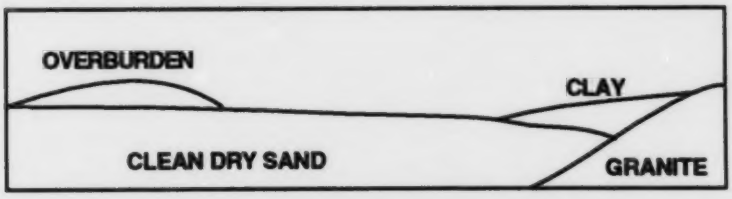
[7] Brohm, D.R. and Katona, Z.L. 1986; Computerized Aggregate Information System: Field Work to Contract Sources List, in 1986 Roads and Transportation Association of Canadian Annual Conference Proceedings, Volume 1, pp.C21-C42.

Appendix A

Data Presentation

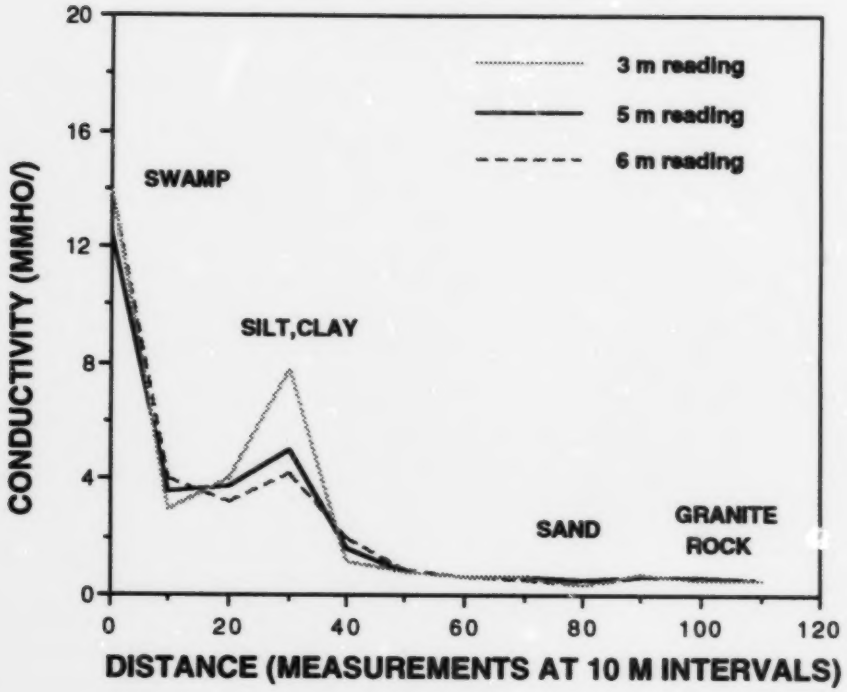
FIGURE 1. ICE-CONTACT DEPOSIT, LINE 1, CARLYLE TOWNSHIP, N. ONT.

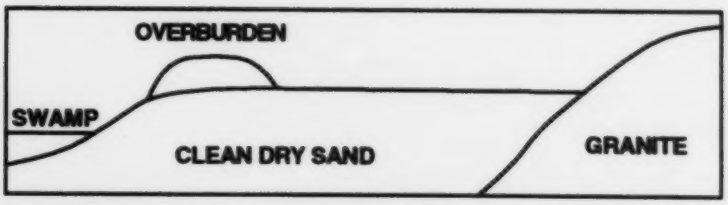




INTERPRETED SCHEMATIC CROSS-SECTION

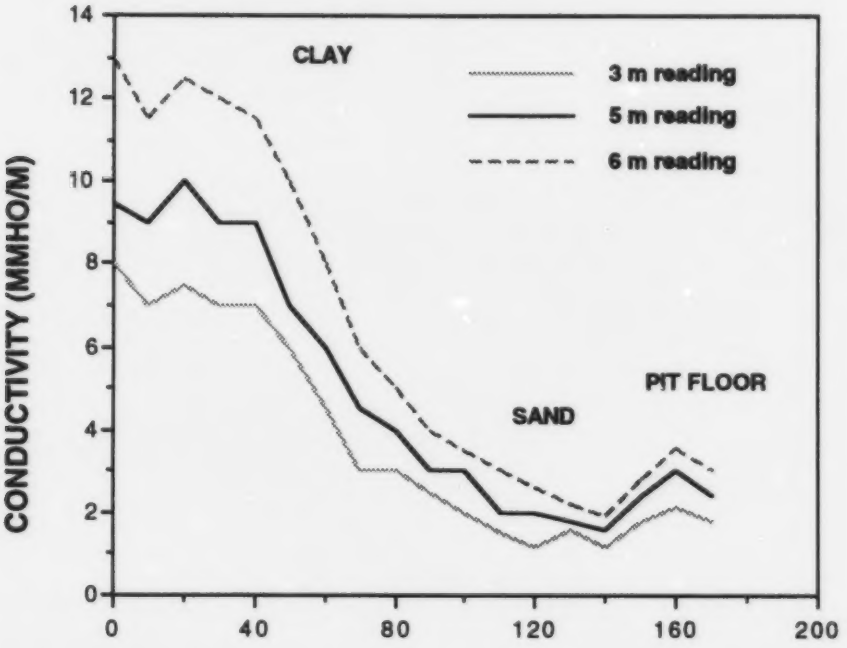
FIGURE 2. ICE-CONTACT DEPOSIT, LINE 2, CARLYLE TOWNSHIP, N. ONT.

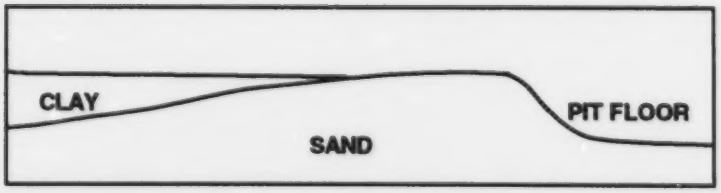




INTERPRETED SCHEMATIC CROSS-SECTION

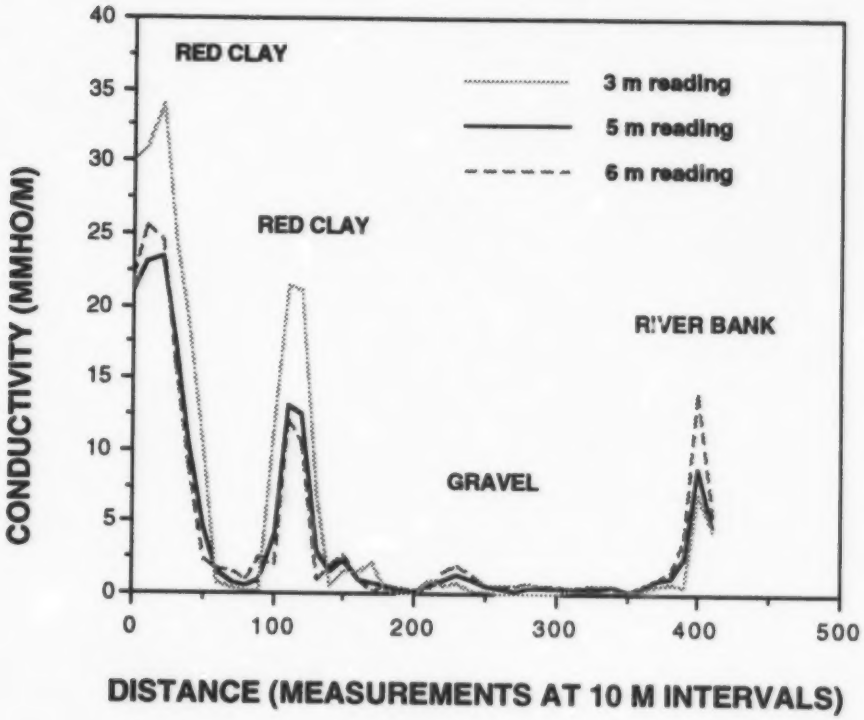
FIGURE 3. LACUSTRINE PLAIN DEPOSIT, LINE 1, OLIVER TOWNSHIP MUNICIPALITY, N. ONT.

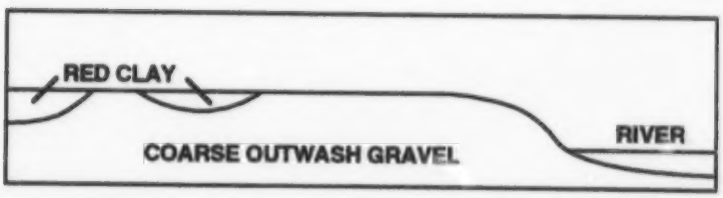




INTERPRETED SCHEMATIC CROSS-SECTION

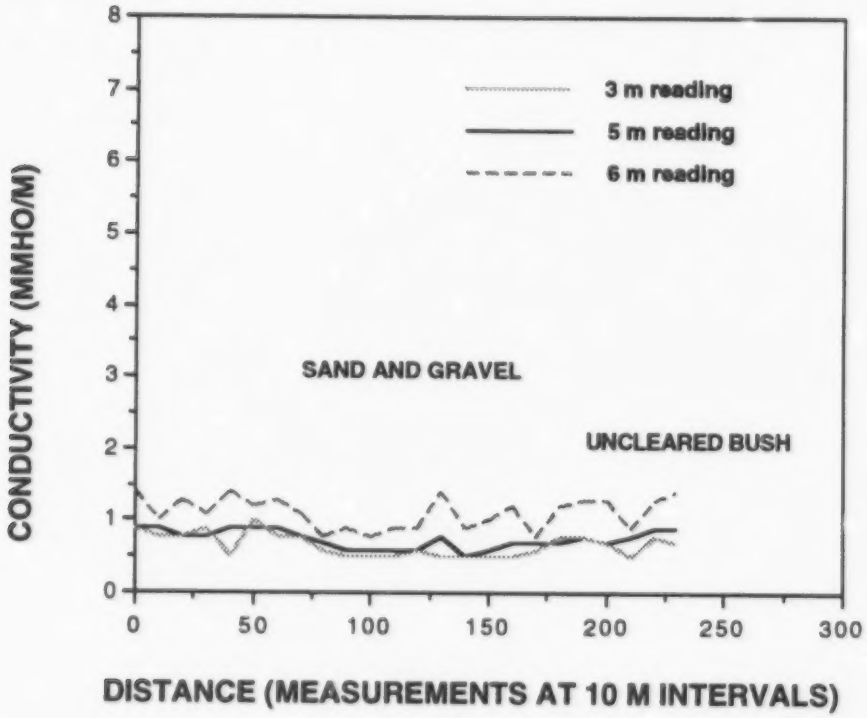
FIGURE 4. ESKER-KAME COMPLEX, LINE 1, GOLDIE TOWNSHIP, N. ONT.

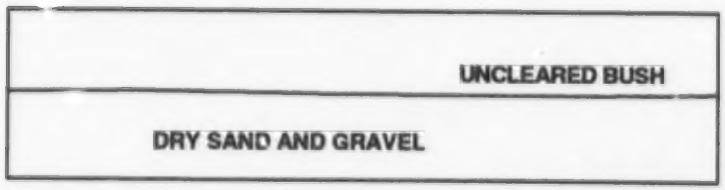




INTERPRETED SCHEMATIC CROSS-SECTION

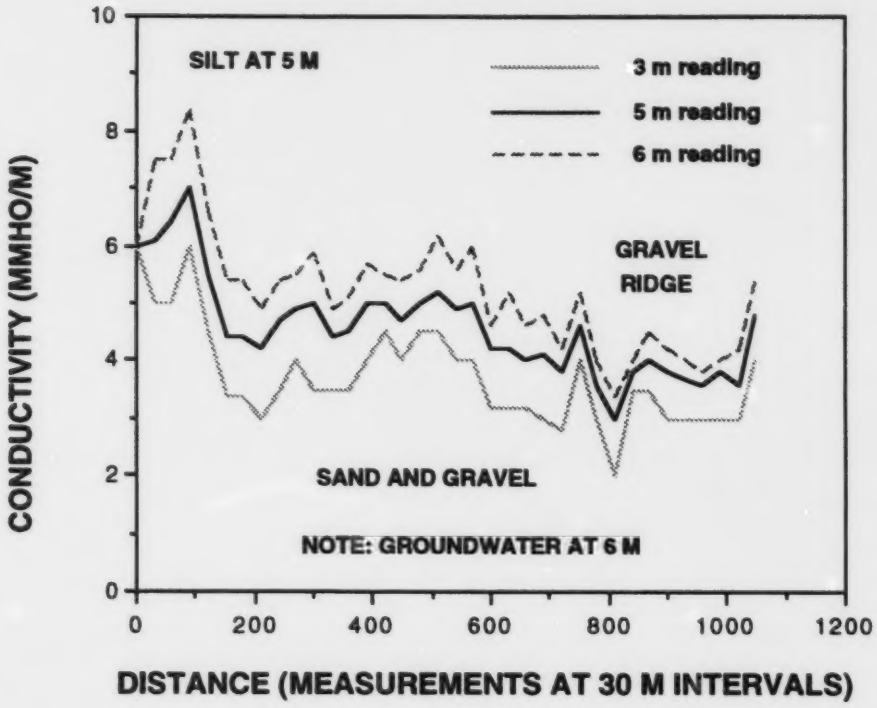
FIGURE 5. ESKER-KAME COMPLEX, LINE 2, GOLDIE TOWNSHIP, N. ONT.

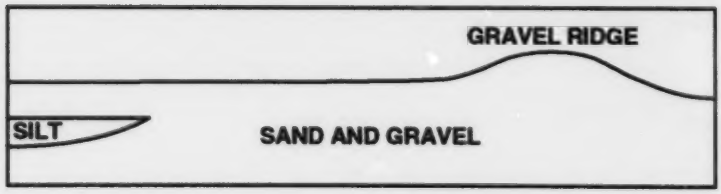




INTERPRETED SCHEMATIC CROSS-SECTION

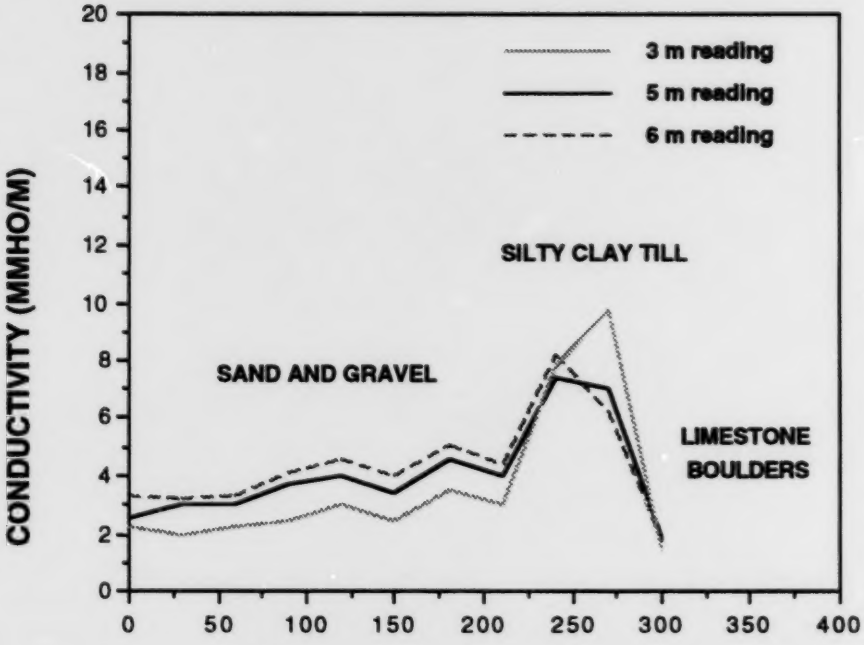
FIGURE 6. OUTWASH DEPOSIT, LINE 1, SULLIVAN TOWNSHIP, S. ONT.

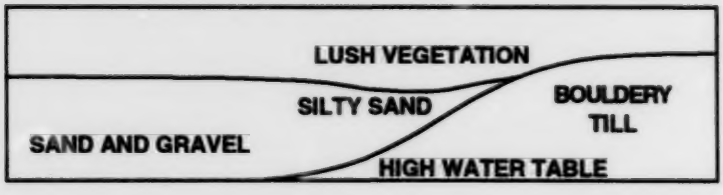




INTERPRETED SCHEMATIC CROSS-SECTION

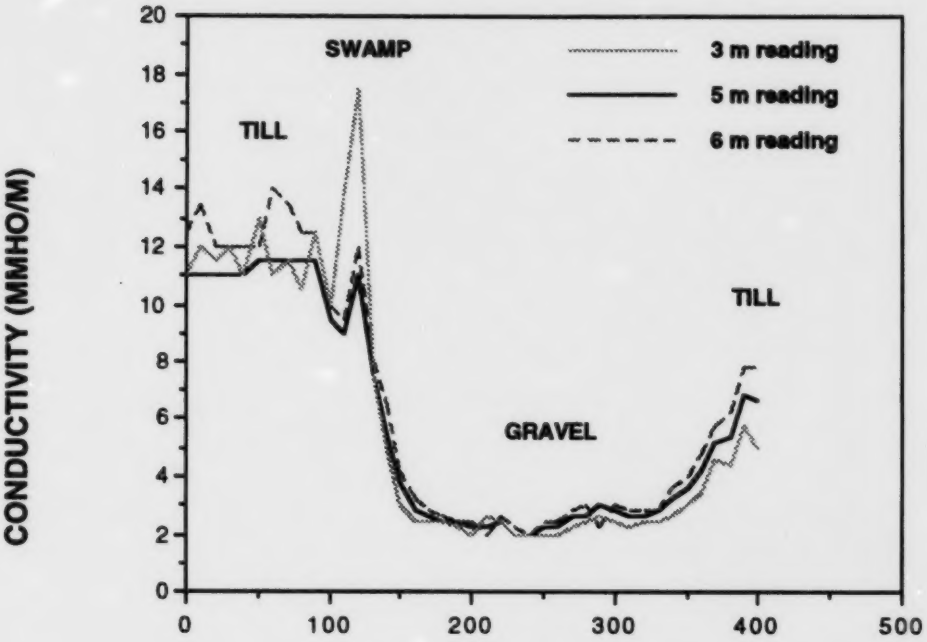
FIGURE 7. OUTWASH DEPOSIT, LINE 2, SULLIVAN TOWNSHIP, S. ONT.

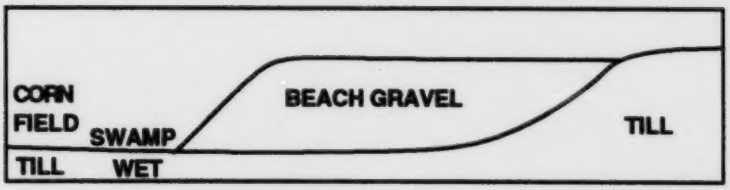




INTERPRETED SCHEMATIC CROSS-SECTION

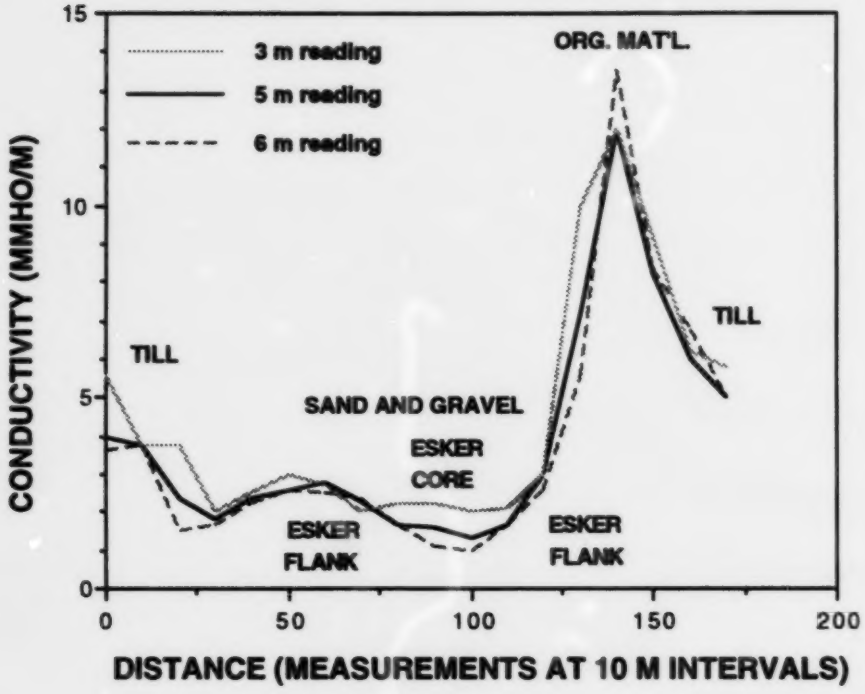
FIGURE 8. BEACH DEPOSIT, LINE 1, SIDNEY TOWNSHIP, S. ONT.

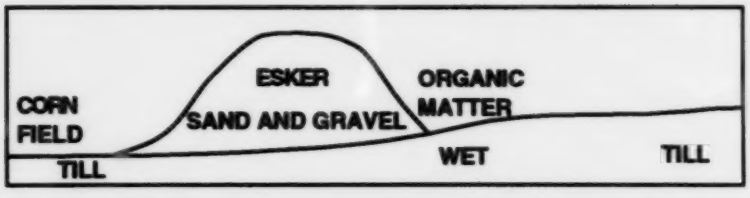




INTERPRETED SCHEMATIC CROSS-SECTION

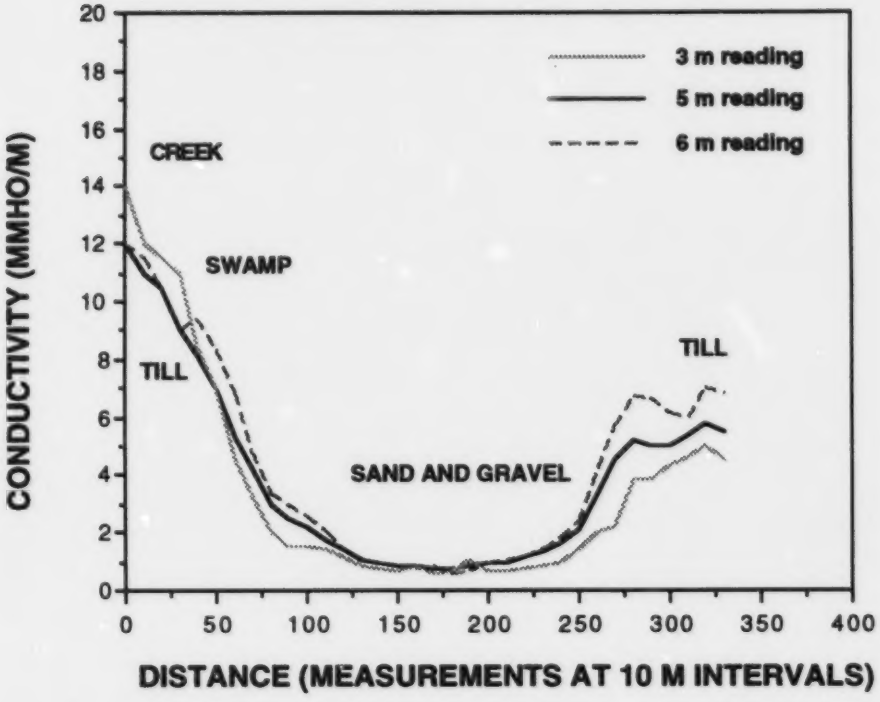
FIGURE 9. ESKER DEPOSIT, LINE 1, SIDNEY TOWNSHIP, S. ONT.

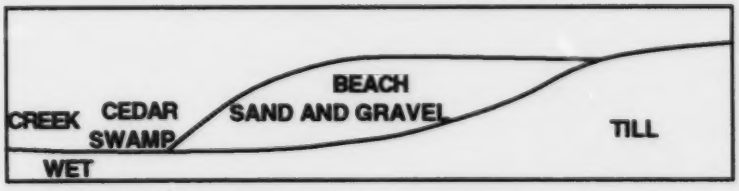




INTERPRETED SCHEMATIC CROSS-SECTION

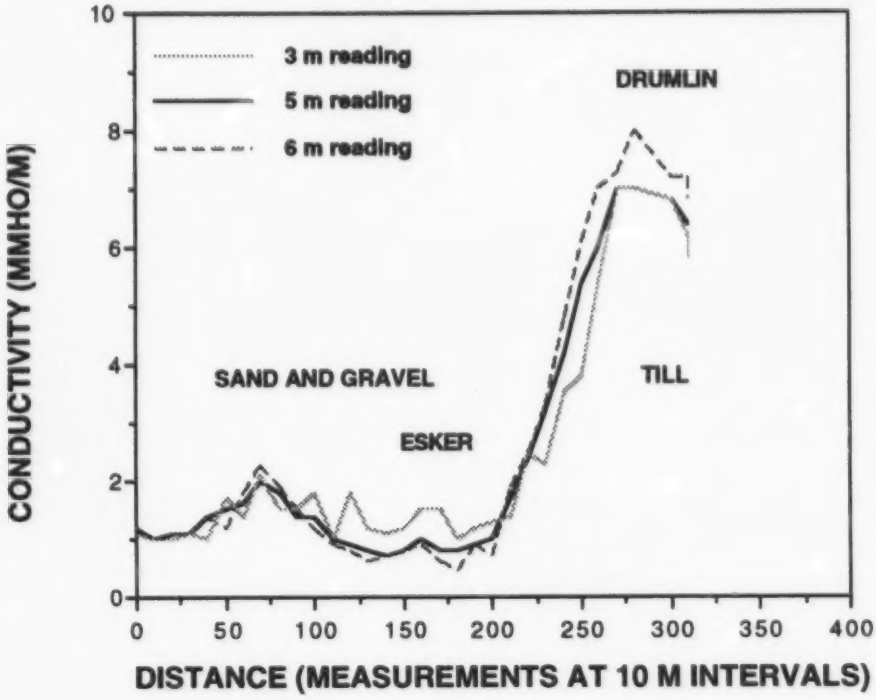
FIGURE 10. BEACH DEPOSIT, LINE 1, BRIGHTON TOWNSHIP, S. ONT.

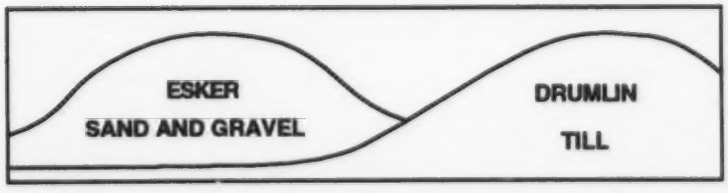




INTERPRETED SCHEMATIC CROSS-SECTION

FIGURE 11. ESKER-DRUMLIN COMPLEX, LINE 1, ASPHODEL TOWNSHIP, S. ONT.





INTERPRETED SCHEMATIC CROSS-SECTION

Photograph 1: EM-31 Survey, 3 m Ground Penetration Reading

Photograph 2: EM-31 Survey, 5 m Ground Penetration Reading

Photograph 3: EM-31 Survey, 6 m Ground Penetration Reading

Photograph 4: Correlation of EM-31 Survey Data with Test Pit